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BUREAU OF WASTE MANAGEMENT
REMEDIATION DIVISION

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GUIDANCE FOR GROUNDWATER MONITORING FOR DEMONSTRATING COMPLIANCE WITH THE CONNECTICUT REMEDIATION STANDARD REGULATIONS

Prepared by the EPOC Technical Practices Work Group on Groundwater Monitoring and the Connecticut Department of Environmental Protection
March 17, 2006

Objectives

The objectives of this guidance document are to:

- summarize and provide commentary on the groundwater monitoring requirements established in the Department of Environmental Protection (DEP) Ground-water Remediation Standards portion of the Remediation Standard Regulations [(RSRs); i.e., Section 22a-133k-3], to clarify issues that may be encountered when applying the standards;

- summarize DEP expectations and current industry practice relating to certain circumstances that could warrant additional groundwater monitoring above and beyond the minimum required monitoring prescribed by the RSRs, and to provide the basis/rationale for such expectations and practices; and

- draw distinctions, where pertinent, between groundwater monitoring for the purpose of demonstrating compliance with RSR requirements and groundwater monitoring for the purpose of investigative site characterization.

Format

The organization of this guidance relative to the numbering of sections and subsections follows the organization of the RSRs.

Comments on RSR Section 22a-133k-3 Ground-water Remediation Standards

(a) General

(1) Two types of groundwater monitoring requirements are established in the RSRs.

Compliance monitoring is required for all groundwater plumes, but it is not required when the absence of a groundwater plume has been adequately demonstrated. Groundwater plumes are defined in the RSRs as groundwater which has been polluted by one or more substances that have been detected in groundwater at a concentration above the analytical detection limit [see Section 22a-133k-1(a)(24)]. The determination of whether or not a plume exists is a site characterization (investigative) activity, and guidance concerning determination of the presence or absence of a plume will be addressed in a future technical guidance document.

Post-remediation monitoring requirements apply (and only apply) in cases where remediation has been performed. In this context, it is important to note that remediation means all types of remediation for soil, as well as for groundwater, including, but not limited to, natural attenuation of groundwater plumes, or the placement of an appropriate ELUR. However, DEP may approve a request to waive post-remediation monitoring for soil remediation completed solely to meet the direct exposure criteria [i.e., requested as an "alternative groundwater monitoring program" in accordance with Section 22a-133k-3(g)(3)(A)].

(2) **Remediation of a ground-water plume in a GA area is required to achieve concentrations less than or equal to the "*background concentration*" for each polluting substance in groundwater.** "Background concentration for groundwater" is defined in the definition section of the RSRs, and determination of such is a site characterization activity. Guidance concerning prevailing industry practices used to determine the background concentration is planned for a future guidance document. In certain circumstances groundwater protection criteria can be used instead of background.

(3) **Remediation of a ground-water plume in a GB area must be sufficient to ensure that *"such ground-water plume does not interfere with any <u>existing</u> use of the ground water."*** Neither "interfere" nor "existing use of the ground water" are defined in the RSRs; however, existing uses most commonly involve one or more of the following: potable or domestic water supply, industrial process water supply, and irrigation supply.

Note:
*In this context, **"existing uses"** in the **RSRs** is not synonymous with **"designated uses"** in the **Water Quality Standards**. For example, as a designated use, groundwater in a GB area is presumed not suitable for human consumption without treatment, though through Section 22a-133k-3(A)(3), the RSRs are protective of existing untreated drinking water uses of groundwater in GB areas. Also, for example, a designated use of groundwater in a GB area under the Water Quality Standards is baseflow for hydraulically-connected surface water bodies, and such baseflow is addressed in the RSRs using surface water protection criteria (not through Section 22a-133k-3(A)(3) covering non-interference with existing uses). Guidance on completing well inventories to determine whether potable (i.e., drinking) water supply wells are in use in the vicinity of a site is being*

prepared by the EPOC/DEP Technical Practices Work Group for Potable Well Inventory Procedures.

Generally, if a plume in a GB area does not result in detected concentrations of plume constituents in the raw (untreated) groundwater withdrawn by any water supply wells (potable, irrigation or process) or other groundwater withdrawals (e.g., from drains) and continued monitoring to demonstrate same is not warranted, then it may be concluded that the plume does not interfere with an existing use of the groundwater. The conclusion that a plume does not detectably impact an untreated water supply may, for example, involve: (i) a demonstrated steady-state plume and consistent lack of impacts in representative samples of the withdrawn water; (ii) significant distance between the steady-state plume and groundwater withdrawal points; (iii) a demonstration that the plume and withdrawal points are located in different aquifers and/or drainage basins which are not hydrogeologically interconnected; or (iv) a demonstration that the withdrawal point is upgradient of the plume during periods of maximum withdrawal.

Generally, if a plume does affect the quality of any untreated groundwater withdrawn by water supply wells or other groundwater withdrawals, or continued monitoring to demonstrate the same is warranted, then the plume *may* interfere with an existing use of the groundwater, and additional evaluation is necessary to assess if the quality impacts actually interfere with such use.

Generally, once an existing use of groundwater is permanently discontinued (e.g., by abandoning a contaminated well and providing an alternate clean water supply), interference with such prior existing use has then been eliminated. Possible future uses (e.g., wells that may be installed in the future) are not “existing uses.”

Conclusions regarding possible interference with an existing use of groundwater are most appropriately made on a case-by-case basis due to the varied and case-specific circumstances involved. It is important to clearly and completely document the rationale for such conclusions.

(b) Surface-water protection criteria

(1) This section pertains to remediation of a *“ground-water plume which discharges to a surface water body…”* The determination as to whether a plume discharges to a surface water body (e.g., stream or wetlands) is a site characterization activity, not a compliance or post-remedial monitoring activity.

- If a plume is not in steady-state and is migrating toward a surface water body, then investigative monitoring sufficient to evaluate whether the plume will or may enter the surface water body is required. Based on the findings of such investigative monitoring, compliance monitoring requirements and possibly post-remediation monitoring requirements could apply.

- If a plume *is* determined to discharge to a surface water body, then compliance monitoring requirements apply.

- If plume remediation is required to attain compliance with groundwater remediation standards, then post-remediation monitoring requirements apply.

(2) This section prescribes more stringent surface-water protection criteria for groundwater plumes that discharge to wetlands or intermittent streams. The reason for the more stringent criteria is that there is less dilution from surface water in wetlands, intermittent streams, headwaters, tidal flats, etc.

The word "*applicable"* referred to in 22a-133k-3(b)(2) with respect to aquatic life criteria refers to <u>chronic</u> (not acute) criteria pertinent to organisms living in fresh water versus saline water, as applicable. If brackish water is encountered use the more stringent of fresh or saline criteria because in brackish water there is a mix of freshwater dwelling organisms and saline water dwelling organisms.

(3) Alternative surface-water protection criteria

(A) Guidance pertaining to determining the "7Q10" low flow metric at a particular location along a stream is presented in Appendix A [Connecticut Water Resources Bulletin No. 34, "A Method for Estimating the 7-day, 10-year Low Flow of Streams in Connecticut," by Cervione, et al., 1982].

(B) Guidance on how to determine/evaluate alternative surface-water protection criteria, particularly for groundwater plume discharges to lakes and tidally-influenced surface water bodies, is planned for a future guidance document.

(c) Volatilization criteria

(1) To clarify, ground water polluted with a volatile organic substance "within 15 feet of…a building" is intended to be measured <u>vertically beneath</u> the building (not horizontally), and the measurement should be made beneath the lowest building level contacting soil and overlying a VOC groundwater plume [i.e., measured 15 feet below the lowest (e.g., basement) floor].

(2) Complexities associated with interpretation and application of this section have not been identified to date, therefore guidance and commentary are not presented at this time.

(3) Complexities associated with interpretation and application of this section have not been identified to date, therefore guidance and commentary are not presented at this time.

(4) Complexities associated with interpretation and application of this section have not been identified to date, therefore guidance and commentary are not presented at this time.

(5) Complexities associated with interpretation and application of this section have not been identified to date, therefore guidance and commentary are not presented at this time.

Note:
The DEP has developed draft revised volatilization criteria that, as of the date of this guidance, have not been formally proposed or promulgated through the regulatory process. However, DEP currently plans to include the revised criteria in an upcoming revision of the RSRs. Additionally, on a site-specific basis, the DEP Commissioner may require use of non-RSR criteria as authorized by Section 22a-133k-3(i). In determining whether site environmental conditions meet the RSRs, environmental professionals should recognize that evaluation of risks posed by vapor plumes involves evolving science and technology, and use of toxicity data and models of variable reliability that are subject to change over time. LEPs must also meet the Professional Conduct provisions of the LEP regulations (RCSA Section 22a-133v-6) as relating to professional competency, holding paramount the health, safety, and welfare of the public and the environment, and making good faith and reasonable efforts to identify and obtain relevant data.

(d) Applicability of Ground-water Protection Criteria

This subsection prescribes certain circumstances in GA areas where the applicable remediation standard is the sometimes less stringent ground-water protection criteria (GWPC) rather than the sometimes more stringent background concentration.

(1) *Reminder:* The "default" groundwater remediation standard in GA areas is background, not the GWPC (refer to General Section 22a-133k-3(a)(2)), though if the provisions of this subdivision are met, the GWPC may be used as the standard in lieu of background.

(2) Section 22a-133k-3(d)(2) allows the use of the GWPC as the standard (in lieu of background), specifically for steady state or diminishing plumes: (i) that are dilute to the point that there are no exceedances of GWPC; and (ii) for which active groundwater remediation has not been used to attain such dilute condition.

Question 1: Does "any ground-water remediation" mean "any," including by natural attenuation?

Answer 1: Yes, natural attenuation is considered to be a remediation method.

Question 2: For a plume that at some point in time contained a substance at a concentration exceeding the GWPC, but through natural attenuation the plume later meets the GWPC, could GWPC be used as the remediation standard?

Answer 2: Possibly, but not in accordance with Section 22a-133k-3(d)(2). The self-implementing "Exemption from Background Due to Technical Impracticability" under Section 22a-133k-3(e)(1) may be used to make the GWPC applicable in this case. Under Section 22a-133k-3(e)(1), it must be demonstrated that it is "technically impracticable" to remediate the plume from GWPC to background, and in this context "technically impracticable" covers, among other circumstances: a determination that, following remediation (including through natural attenuation), the plume degree and extent are in steady state, or the plume extent is not increasing and the concentration trend for a substance is downward and asymptotic.

So, for a plume that historically contained a substance at a concentration exceeding the GWPC, but through natural attenuation (or any other remediation method), now does not contain a substance at a concentration exceeding the GWPC, the GWPC may be used as the remediation standard so long as the plume degree and extent are in steady state or diminishing (i.e., the plume extent is not increasing and the concentration trend for a substance is downward and asymptotic).

Question 3: What groundwater monitoring requirements remain after it has been demonstrated in accordance with section 22a-133k-3(d)(2), that "the extent of the groundwater plume is not increasing over time and, except for seasonal variations, the concentration of the subject substance in such ground-water plume is not increasing at any point over time?"

Answer 3: Section 22a-133k-3(d)(2) prescribes the compliance standard that may be used (i.e., GWPC) for a circumstance that by definition does not require groundwater remediation. Accordingly, compliance monitoring in accordance with Section 22a-133k-3(f)(1) is required, but post-remediation monitoring is not required under this scenario/provision.

Question 4: What groundwater monitoring requirements remain after it has been demonstrated in accordance with Section 22a-133k-3(e)(1), that a steady state (or diminishing plume) condition exists such that further remediation is technically impracticable?

Answer 4: Section 22a-133k-3(e)(1) is a self-implementing exception that may be used, for example, for cases where remediation (including natural attenuation remediation) has been used to meet the GWPC. Accordingly, compliance monitoring in accordance with Section 22a-133k-3(f)(1) is required, followed by post-remediation monitoring in accordance with Section 22a-133k-3(g)(3)(i).

Question 5: What amount of groundwater monitoring would generally be considered sufficient to demonstrate that "the extent of the groundwater plume is not increasing over time and, except for seasonal variations, the concentration of the subject substance in such ground-water plume is not increasing at any point over time" (i.e., that a steady state or diminishing plume condition exists)?

Answer 5: The amount of monitoring depends on several factors, including but not limited to the age of the plume, the length of time covered by existing monitoring data, the layout of the monitoring well network, the distance from the edge of the plume to potential receptors, documented trends in contaminant concentrations, and contaminant concentrations in the plume relative to the applicable and pertinent regulatory standards.

Assuming a plume is adequately characterized by an existing monitoring well network, a minimum of two years of semi-annual monitoring could be sufficient, with such monitoring preferably coinciding with typical seasonal high water table periods (typically March and April) and seasonal low water table periods (typically August and September). A minimum of one year of quarterly monitoring could also be sufficient (e.g., for cases involving a very old release with plume concentrations far below compliance criteria). Other monitoring programs could also be sufficient, depending on the site-specific circumstances. An environmental professional needs to clearly and completely document the rationale for concluding that the monitoring program is sufficient to demonstrate that "the extent of the groundwater plume is not increasing over time and, except for seasonal variations, the concentration of the subject substance in such ground-water plume is not increasing at any point over time."

Note:
The investigative monitoring used to determine which standard applies and/or whether steady state (or diminishing plume) conditions exist, may also be used for the additional purpose of satisfying in whole or in part compliance monitoring requirements (i.e., the same data may be used for dual purposes). However, in GA areas, post-remediation monitoring must be initiated after compliance monitoring has been completed, so neither upfront investigative monitoring nor compliance monitoring may be additionally used to meet post-remediation monitoring requirements (unless one receives Commissioner approval of an alternate groundwater monitoring program), though this is not the case for GB areas [refer to discussions on Sections 22a-133k-3(f) and (g]).

(3) In GB areas, the GWPC apply to groundwater used for drinking or other domestic purposes (e.g., GWPC apply to the water withdrawn from residential irrigation wells). Water supply wells may be in use in GB areas, and an inventory provides the information needed to determine whether such wells are in use and therefore that GWPC apply to the water withdrawn by those wells. It is DEPs expectation and common current industry practice to complete domestic water well inventories for sites in GB areas. Such practice stems from the need to meet the Professional Conduct provisions of the LEP regulations (RCSA Section 22a-133v-6) as relating to professional competency, holding paramount the health, safety and welfare of the public and the environment, and making good faith and reasonable efforts to identify and obtain relevant data.

(e) Technical Impracticability of Ground-water Remediation

Comments regarding one use of Section 22a-133k-3(e) are presented on page 5.

(f) and (g) – Compliance Monitoring and Post-Remediation Monitoring

RSR Sections 22a-133k-3(f) (addressing "compliance monitoring") and 22a-133k-3(g) (addressing "post-remediation monitoring") are reportedly the portions of the RSRs most subject to differing interpretation and inconsistent application, likely because:

- The sections are complex, sometimes interdependent, and have different triggers, monitoring objectives, durations and frequencies; and

- Groundwater monitoring is often most extensively completed for site characterization (investigative) purposes, though in some cases this investigative monitoring is not needed for compliance monitoring and/or post-remediation monitoring purposes, while in other cases, groundwater quality data obtained for one purpose may be used for other purposes (e.g., investigative monitoring used as part of the data set to demonstrate compliance with the groundwater remediation standards; compliance monitoring used additionally for post-remedial purposes).

Please note that the RSRs specify *minimum* compliance monitoring and post-remediation monitoring requirements, and that LEPs (and/or DEP) may require additional monitoring beyond the minimal required amount, as needed, to meet project-specific objectives in light of such items as: (i) existing data, data trends, potential receptors, and how close the compliant groundwater quality data are to the applicable and pertinent standards; and (ii) an LEP's need to meet the Professional Conduct provisions of the LEP regulations (RCSA Section 22a-133v-6) as relating to professional competency, holding paramount the health, safety and welfare of the public and the environment, and making good faith and reasonable efforts to identify and obtain relevant data.

Recognizing that each site must be investigated in accordance with "prevailing standards and guidelines" before compliance with the RSRs can be demonstrated, there are two RSR-related purposes for groundwater monitoring, as follows:

- Demonstration of compliance with criteria in regulations (i.e., "compliance monitoring" under Section 22a-133k-3(f)); and

- Demonstration of the effectiveness of remediation (i.e., "post-remediation monitoring" under Section 22a-133k-3(g)).

Site Characterization Monitoring

The topic of site characterization groundwater monitoring is generally beyond the scope of this guidance document. Please refer to DEP's Site Characterization Guidance Document.

Compliance Monitoring

Compliance monitoring under Section 22a-133k-3(f) is required **if** one has identified the presence of a groundwater plume. This underscores the importance of groundwater quality investigations relating to identifying the presence/absence of a groundwater plume (s) during site characterization. [Note: Refer to the definitions section of the RSRs for the definition of a "ground-water plume." Therefore, any detected level of a volatile organic compound, or a dissolved metal concentrations above the natural background concentration for that metal, would indicate the presence of a plume.]

The RSRs prescribe the following *minimum* compliance monitoring durations/frequencies, as follows:

Regulations Section	Duration/frequency	Sampling Objective
22a-133k-3(f)(1)(A)	4 consecutive quarters	to attain compliance with GWPC in circumstances where all locations within the plume meet the GWPC
22a-133k-3(f)(1)(B)	12 consecutive months	to attain compliance with GWPC in circumstances where the 95% UCL of the mean meets the GWPC
22a-133k-3(f)(2)(A)	4 consecutive quarters	to attain compliance with SWPC in circumstances where the average concentration of the plume meets the SWPC
22a-133k-3(f)(2)(B)	The monitoring duration and frequency are not prescribed.	Under this section a steady state or diminishing plume condition must be demonstrated to attain compliance with the SWPC at the downgradient edge (or discharge edge) of the groundwater plume. *Note: The Q&As for Section 22a-133k-3(d) provide guidance on groundwater monitoring for the purpose of demonstrating steady state or diminishing plume conditions.*
22a-133k-3(f)(3)(A)	4 consecutive quarters	to attain compliance with the volatilization criteria (VC) in circumstances where the 95% UCL of the mean meets the VC

Regulations Section	Duration/frequency	Sampling Objective
22a-133k-3(f)(3)(B)	The monitoring duration and frequency are not prescribed for circumstances where the VC are met at all locations. *Note: Additional commentary regarding volatilization criteria are provided under Section 22a-133k-3(c).* Additional commentary regarding information to consider for plume characterization is presented in the questions and answers under section 22a-133k-3(d).	*Note: Some could interpret this to mean that only one sampling round is required. Generally, however, a minimum of two monitoring rounds would be considered necessary to verify the absence of, or concentrations in, a groundwater plume or soil vapor plume impacted by VOCs.*

Post-remediation Monitoring

Sections 22a-133k-3(g)(1) and (2) describe the objectives for post-remediation groundwater monitoring (post-remediation monitoring) in GA and GB areas, respectively.

Section 22a-133k-3(g)(3) specifies the minimum required duration of post-remediation monitoring, with a distinction drawn between GA areas (one year after the background concentration has been attained, or three years after the GWPC has been attained) and GB areas (two years).

Note: DEP will consider requests for alternate groundwater monitoring plans involving one year of post-remediation monitoring for GB areas, provided that the remaining monitoring requirements are met. However, a minimum of two years of post-remediation monitoring is often necessary in GB areas to document compliance with the SWPC under 22a-133k-3(f)(2)(B), where steady state or diminishing plume conditions must be demonstrated (e.g., using two years of seasonal semi-annual monitoring).

The RSRs do not specify a frequency for post-remediation monitoring. The frequency for post-remediation monitoring is to be based on judgment and must be sufficient to demonstrate that monitoring objectives have been met, taking into account the level of confidence required and the degree of risk associated with the site-specific circumstances. It is generally recognized that a quarterly sampling frequency is nearly always sufficient (i.e., as a conservative "rule of thumb" default frequency). However, seasonal semi-annual monitoring (during the seasonal high water table and seasonal low water table periods) and other monitoring programs, depending on site-specific circumstances, could also be sufficient. Additional commentary regarding information to consider for plume characterization is presented in the questions and answers under Section 22a-133k-3(d). It is important to clearly and completely document the rationale for conclusions regarding the sufficiency of groundwater monitoring programs used to demonstrate that monitoring objectives have been met.

Under Section 22a-133k-3(g)(3)(A)(i) and (ii), in GA areas, post-remediation monitoring must be performed after compliance monitoring has been completed. Therefore, in GA areas where remediation was required to attain compliance with applicable RSRs, a minimum of one year of compliance monitoring is followed by a minimum of either one year or three years of post-remediation monitoring, depending on whether background concentrations were achieved (for a minimum total of two or four years of monitoring for compliance monitoring plus post-remediation monitoring), unless a request to discontinue such monitoring earlier or to use an alternate monitoring program is approved by the DEP.

Under Section 22a-133k-3(g)(3)(B), in GB areas, post-remediation monitoring may be discontinued two years after cessation of all remediation required to meet applicable criteria if (not after) SWPC and VC have been met under 22a-133k-3(f), and groundwater is suitable for all existing uses. Therefore, in GB areas where remediation was completed to attain compliance with applicable RSRs, typically one or two years of compliance monitoring will be completed, which may also serve as all or part of a post-remediation monitoring program, provided that all such monitoring is completed after cessation of such remediation (commonly resulting in a minimum total of two years of monitoring for compliance monitoring plus post-remediation monitoring purposes), unless a request to discontinue such monitoring earlier or to use an alternate monitoring program is approved by the DEP.

Question 6: Is post-remediation monitoring required when remediation has not been needed to attain compliance with applicable criteria?

Answer 6: No. However, in some cases, additional monitoring may be warranted beyond the minimal compliance monitoring required by the RSRs. For example, if the plume concentrations are below, but near, the compliance standard, or there is an increasing trend in plume concentrations, the LEP should consider whether additional investigative and/or compliance monitoring should be done in his/her judgment to meet site characterization and/or compliance monitoring purposes, and/or to meet the requirements of the Rules of Professional Conduct under the LEP regulations. Also, as needed to protect human health and the environment, the DEP could require additional monitoring, as authorized by Section 22a-133k-3(i).

Question 7: Is there a provision in the RSRs for an LEP to request a DEP waiver from compliance monitoring for a release area or potential release area in which sufficient investigations have been completed and the presence of a plume has not been detected?

Answer 7: No. Plume investigations for site characterization purposes are not prescribed by the RSRs. Rather, such investigations must be completed in accordance with prevailing standards and guidelines and must be judged sufficient by the LEP based on the site-specific circumstances regarding the level of confidence required and the degree of risk associated with the release. The LEP's conclusion may be reviewed (and audited) by the DEP following the submission of LEP verification.

Question 8: Are the constituents of concern always the same for compliance monitoring and post-remediation monitoring?

Answer 8: No. For example, substances for which remediation was not required to attain compliance with the RSRs would not typically be included in post-remediation monitoring programs. Compliance monitoring is focused on all contaminants of concern released and detected in groundwater; while post-remediation monitoring is primarily focused on constituents that triggered remediation.

(h) Additional Polluting Substances

This section states, "With respect to a substance in ground water for which a ground-water protection criterion is not specified in Sections 22a-133k-1 through 22a-133k-3, inclusive, of the Regulations of the Connecticut State Agencies, the Commissioner may approve in writing a ground-water protection criterion to apply to such substance." Additionally, this Section describes the information that persons requesting approval of the criterion must provide to the Commissioner for review, information the Commissioner shall consider before approving the proposed ground-water protection criterion and the equation to be used in calculating the ground-water protection criterion (depending on whether the substance is carcinogenic or non-carcinogenic).

Section 22a-133k-1(a)(23) defines "Ground-water protection criteria" to be "the concentrations identified in Appendix C to Sections 22a-133k-1 through 22a-133k-3 of the Regulations of Connecticut State Agencies.

Question 9: How should LEPs address substances in groundwater for which ground-water protection criteria, surface-water protection criteria and/or volatilization criteria have not been established?

Answer 9: LEPs should address such substances taking cognizance of the Professional Conduct provisions of the LEP regulations (RCSA Section 22a-133v-6) relating to professional competency, holding paramount the health, safety and welfare of the public and the environment, and making good faith and reasonable efforts to identify and obtain relevant data. For ground-water protection criteria and volatilization criteria, LEPs should consider whether to seek Commissioner approval of new criteria for such substances based on pertinent information (e.g., regarding the source, concentration of the substance detected in groundwater, its possible or probable toxicity, the quality and reliability of the currently-available toxicity data, the substance's solubility in water, the Henry's law constant for the substance, and the calculated criterion using the appropriate RSR formula).

Examples where it would be appropriate for an LEP to not request that the DEP Commissioner approve a ground-water protection criterion for the substance would include those substances with relatively low toxicity and substances for which the calculated criteria exceeds the solubility of the substance in groundwater. As another example, if the detected substance was sought because it was part of a particular industrial process that would otherwise not be reported as part of a "standardized" laboratory report, the LEP should request that the DEP Commissioner approve a new ground-water criterion for the substance, so long as reliable toxicity data are available and the substance's toxicity warrants such. However, if the detected substance is a common constituent of No. 2 fuel oil that happens to be reported as a tentatively identified compound and the toxicity of similar substances is low, then the LEP may appropriately decide to not request DEP Commissioner approval of a ground-water protection criterion for the substance. Volatilization criteria are generally not pertinent to relatively non-volatile substances such as metals, PCBs, and PAHs. Additionally, it is generally not necessary for an LEP to request DEP Commissioner approval of a volatilization criterion for volatile organic compounds that are very soluble in water and with relatively low toxicity. As for all important decisions relying on an LEP's judgment, it is important that the LEP clearly and completely document the rationale for a decision not to request DEP Commissioner approval of a ground-water protection criterion or volatilization criterion for a detected additional polluting substance.

Calculation of additional surface-water protection criteria should focus on any substances that are detected in groundwater plumes discharging to surface water bodies. If such substances are detected in a groundwater plume discharging to surface water and a surface-water protection criteria have not been established by DEP, then the environmental professional should develop surface water protection criteria. DEP is developing a technical guidance document to assist in this circumstance. .

(i) Additional Remediation of Ground Water

This section states, in part, "Nothing in Sections 22a-133k-1 through 22a-133k-3, inclusive, of the Regulations of Connecticut State Agencies shall preclude the Commissioner from taking any action necessary to prevent or abate pollution, or to prevent or abate any threat to human health or the environment."

This section authorizes DEP to require additional action on a site-specific basis. This is sometimes referred to as the "omnibus authority."

This document is designed to answer general questions and provide basic information. You should refer to the appropriate statutes and regulations for the specific language. It is your responsibility to comply with all applicable laws and regulations. The information contained in this guidance document is intended only to acquaint you with certain aspects of the regulations. For further information please contact the Remediation Division at (860) 424-3705.

APPENDIX A

Connecticut Water Resources Bulletin No. 34
A Method for Estimating the 7-day, 10-year Low Flow of Streams in Connecticut
Cervione, et al., 1982

STATE OF CONNECTICUT
DEPARTMENT OF ENVIRONMENTAL PROTECTION

A METHOD FOR ESTIMATING THE 7-DAY, 10-YEAR LOW FLOW OF STREAMS IN CONNECTICUT

By

Michael A. Cervione, Jr. and Robert L. Melvin,
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WATER COMPLIANCE

CONNECTICUT WATER RESOURCES BULLETIN NO. 34

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CONVERSION FACTORS

Factors shown below are used to convert the inch-pound units used in this report to the International System of metric units (SI):

Multiply Inch-pound unit	By	To obtain SI unit
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	3.785×10^3	cubic meters per day (m^3/d)

A METHOD FOR ESTIMATING THE 7-DAY, 10-YEAR LOW FLOW OF STREAMS IN CONNECTICUT

By Michael A. Cervione, Jr., Robert L. Melvin, and Kathleen A. Cyr

ABSTRACT

A method for estimating the 7-day, 10-year low flow of ungaged Connecticut streams is presented in this report. The 7-day, 10-year low flow is the statistical low-flow index most commonly used in Connecticut for water-resources planning and management. The method described is based upon the fact that low flows are sustained by the discharge of water from adjacent aquifers.

An equation for estimating the 7-day, 10-year low flow at an ungaged site on a stream unaffected by man's activities was determined by regression analysis. The analysis related the observed 7-day, 10-year low flow at 27 stream-gaging stations to the areal distribution of each major aquifer in the upstream drainage area. The standard error of estimate is 1.4 cubic feet per second.

The aquifer having the best water-yielding characteristics is coarse-grained stratified drift. Through the use of the regression equation, it is estimated that only 0.15 square mile of coarse-grained stratified drift in a drainage basin can yield a 7-day, 10-year low flow of 0.1 cubic foot per second. The till-mantled bedrock yields significantly lesser amounts of water to streams at times of low flow. However, a 7-day, 10-year low flow of 0.1 cubic foot per second (from the regression equation) can be expected from a drainage basin underlain exclusively by till-mantled bedrock if its upstream drainage area is 10 square miles or more.

INTRODUCTION

The low-flow characteristics of a stream are commonly critically important with respect to water supply, waste disposal, power generation and navigation. During drought, the economic and environmental well being of an entire region can be adversely affected. Water-resource planners and managers need information on the magnitude, frequency, and duration of low streamflows to minimize adverse impacts.

In Connecticut, the lowest annual mean discharge during 7 consecutive days with a recurrence interval of 10 years, is the low-flow index most commonly used in water-resources planning and management. This statistically derived value is termed the "7-day, 10-year low flow"; streamflows are greater than this value about 99 percent of the time in Connecticut streams. The probability of a 7-day low flow being less than the 7-day, 10-year low flow in any given year is 10 percent.

At present, the the 7-day, 10-year low flow information is used mostly by the Connecticut Dept. of Environmental Protection for developing low-flow criteria, which, in turn, are used for water-quality standards (Connecticut Dept. of Environmental Protection, 1980), for evaluating waste-water discharge applications, for siting of treatment plants and sanitary landfills, and for setting minimum release requirements below impoundments. Accordingly, the Connecticut Dept. of Environmental Protection has been engaged in a cooperative program with the U.S. Geological Survey to develop and refine techniques for estimating the 7-day, 10-year low flow of streams in the State.

Purpose and Scope

The 7-day, 10-year low flow can be determined at any site where streamflow has been measured for a sufficient period of time. Mostly, however, the information is needed at ungaged locations. The purpose of this report is to outline a method for estimating the 7-day, 10-year low flow at any site on any stream in Connecticut that is not affected by tide, does not have its flow artificially manipulated during low flow periods, and does not drain an area having an appreciable degree of urbanization. The method is based upon the fact that low flows are sustained by the discharge of water from adjacent aquifers. It utilizes an equation determined from a regression analysis relating the observed 7-day, 10-year low flow at 27 stream-gaging stations to the areal distribution of major water bearing units in the upstream drainage area.

Besides explaining the method used to estimate the 7-day, 10-year low flow at ungaged sites, the report discusses the standard error of estimate and lists the 7-day, 10-year low flow at gaged sites.

HYDROLOGIC FRAMEWORK

Geology, ground water and low flow

In Connecticut, low streamflows are sustained by ground-water discharge. This discharge, termed ground-water runoff, is a major source of streamflow throughout the year, with the exception of periods during and immediately after large storms, when most of the flow may be derived from surface runoff. During protracted dry periods, some aquifers may become depleted, and some streams may not flow. Low streamflows are most common in the growing season when precipitation is generally utilized by plants or to meet soil moisture needs. Streamflows are generally lowest during the latter part of this approximately 6-month period, as shown in figure 1.

The basic hydrologic framework for investigating ground-water contributions to streamflow and other aspects of streamflow variability is the drainage basin. In most parts of the State, the surface-water and ground-water drainage divides are coincident, and the only source of water is precipitation within the area bounded by the drainage divides. The pattern of ground-water circulation in a typical Connecticut drainage basin unaffected by man's activities is shown in figure 2.

Note that in a few areas, principally within north-central Connecticut, the extent of the ground-water flow system may be different from the surface-water drainage area and cannot be defined by topographic drainage divides. In a relatively few other basins, there are interbasin transfers of water. If either condition exists, the drainage basin may not constitute an appropriate framework for low-flow studies without additional information.

The geology of a drainage basin significantly affects the time-distribution of streamflow and particularly the low-flow characteristics. Basins in Connecticut and adjacent parts of New England and New York are underlain by three major water-bearing geologic units or aquifers: stratified drift, till, and bedrock. Stratified drift is an unconsolidated sediment composed of interbedded layers of gravel, sand, silt, and clay. These deposits are generally restricted to valley areas that served as drainage ways for glacial meltwater or were the sites of temporary glacial lakes. The stratified drift in a basin can be further characterized as either "coarse-grained" (dominantly fine sand to gravel), or "fine-grained" (dominantly very fine sand, silt, and clay). Coarse-grained stratified drift has relatively high hydraulic conductivities and storage coefficients and, consequently, has the best water-yielding characteristics of the geologic units. Previous studies summarized by Cervione and others (1972) indicate that in areas directly underlain by this material both average annual recharge from precipitation and average annual ground-water runoff are approximately three times greater than from till and bedrock areas.

Fine-grained stratified drift, conversely, has poor water-yielding characteristics. Information (Ryder and others, 1981) suggests that areas directly underlain by this material are hydrologically similar to till and bedrock, in respect to ground-water runoff to streams. Extensive fine-grained stratified drift is not common except in the north-central part of the State.

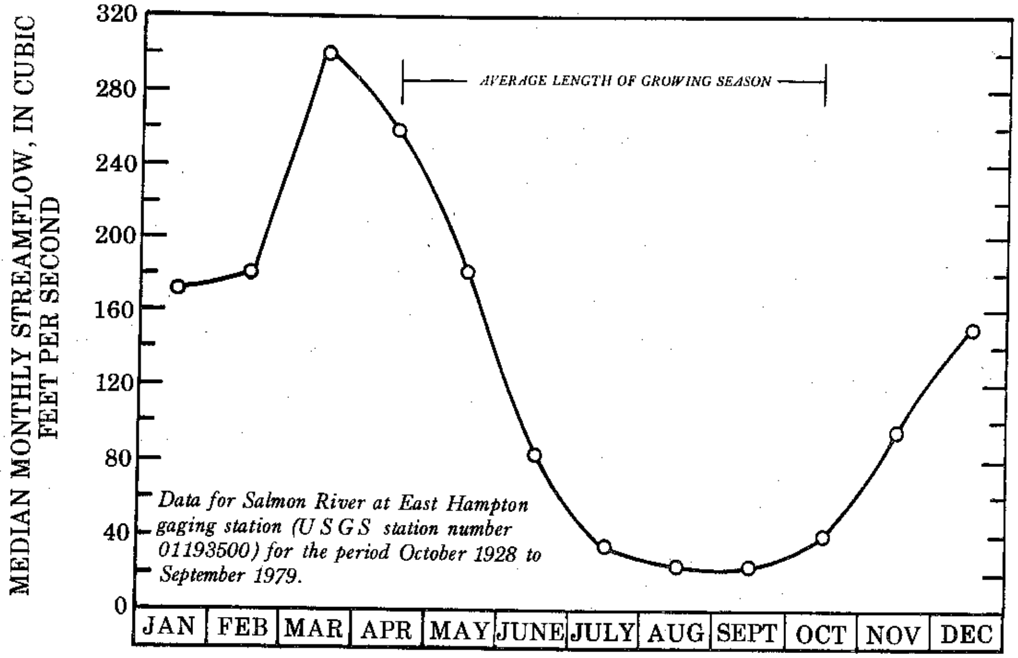
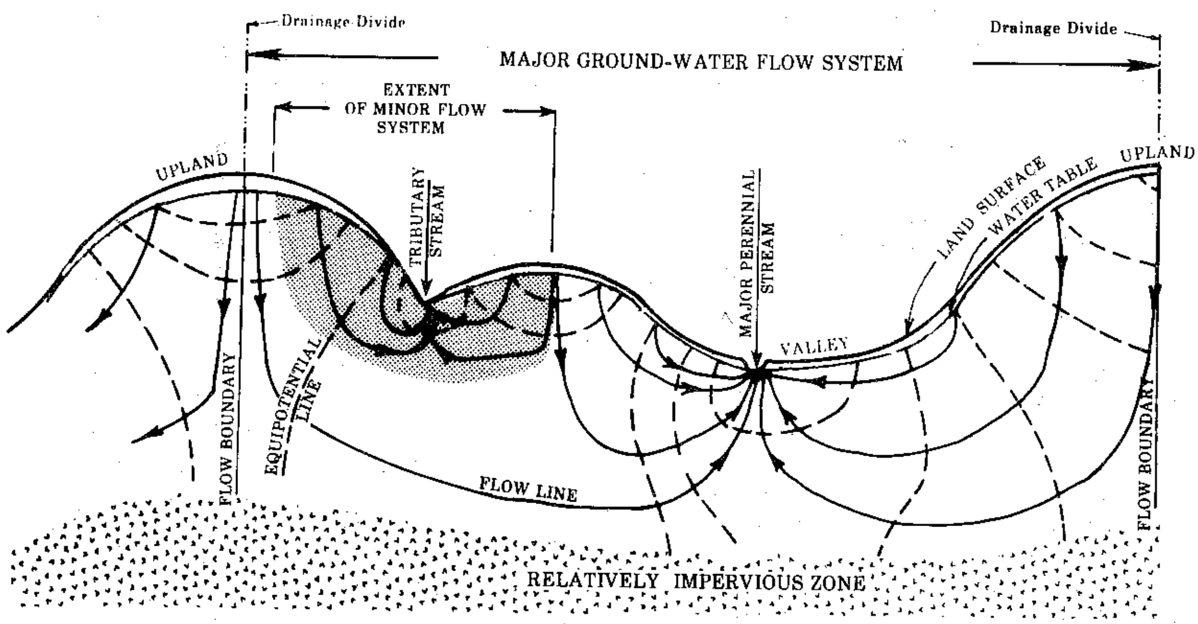


Figure 1.--Seasonal pattern of streamflow in Connecticut

This hydrograph illustrates the typical seasonal pattern of flows. During the growing season, most precipitation is returned to the atmosphere by evaporation and transpiration and there is relatively little surface runoff or ground-water recharge.



Source: Cervione and others (1972)

Figure 2.--Generalized ground-water circulation within a typical Connecticut drainage basin

The direction of ground-water flow and the distribution of hydraulic head are depicted by flow lines and equipotential lines. The actual configuration of these lines is more complex than that shown because of differences in hydraulic conductivity between the subsurface geologic units in the saturated zone and other factors. Minor ground-water flow systems may be present only part of the year.

Till is an unconsolidated, non-stratified heterogeneous sediment, deposited directly by glacial ice. Most bedrock in the State is overlain by till that averages less than 10 feet thick. Bedrock in Connecticut may be aggregated into two general types: crystalline bedrock that includes a variety of metamorphic and igneous rocks, and sedimentary bedrock, composed predominantly of sandstone and shale that underlies the central part of the State. Bedrock of one type or another underlies every drainage basin. In some, it is discontinuously mantled by till, whereas in others, it is covered by both till and stratified drift. Surficial geologic maps, available for almost all parts of the State, show the areal distribution of these units. The Connecticut Dept. of Environmental Protection has recently published an information directory (Henney, 1981) that lists available geologic maps and instructions for obtaining them.

Till and bedrock are considered as a hydrologic unit in subsequent analyses and the unit is termed "till-mantled bedrock." This consolidation is warranted in that both materials have significantly lower average hydraulic conductivities and storage coefficients than coarse-grained stratified drift and hence poorer water-yielding characteristics. From a practical perspective, it is also not possible to differentiate on available geologic maps the areas underlain only by exposed bedrock from those where the bedrock is overlain by saturated or unsaturated till. Where fine-grained stratified drift has been mapped as the surficial geologic unit, it has also been included in the "till-mantled bedrock" hydrologic unit.

Ground-water contributions to streamflow are governed principally by the transmissivity (average hydraulic conductivity times saturated thickness) and storage coefficient of the water-yielding units, the average hydraulic gradient, and the area of stream channel through which the ground water discharges. Another factor not considered in this or previous studies is differences in the quantity of ground-water evapotranspiration from one basin to another. If all other conditions were equal, the differences in ground-water runoff to streams from one site to another would be proportional to differences in the quantity of ground-water evapotranspiration in the upstream drainage areas.

M. P. Thomas' study of the relationship between surficial geology and the time-distribution of streamflow (Thomas, 1966) was the first to quantify the relationship between geology of a drainage area and the magnitude and frequency of low flows in Connecticut. In this study, flow-duration curves (cumulative frequency curves showing the average period of time specific daily flows are equaled or exceeded) from several continuous record stream-gaging stations were evaluated with respect to the geology of the drainage basin. The results, summarized in a family of flow-duration curves, are shown in figure 3.

The lower part of these curves (flows equaled or exceeded 80 to 99.9 percent of the time) show that the magnitudes of low flows are related to the relative percentage of the drainage area directly underlain by coarse-grained stratified drift rather than till-mantled bedrock. As pointed out by Thomas, the relatively large ground-water runoff from stratified drift is a reflection of its large infiltration and storage capacity and its ability to transmit water.

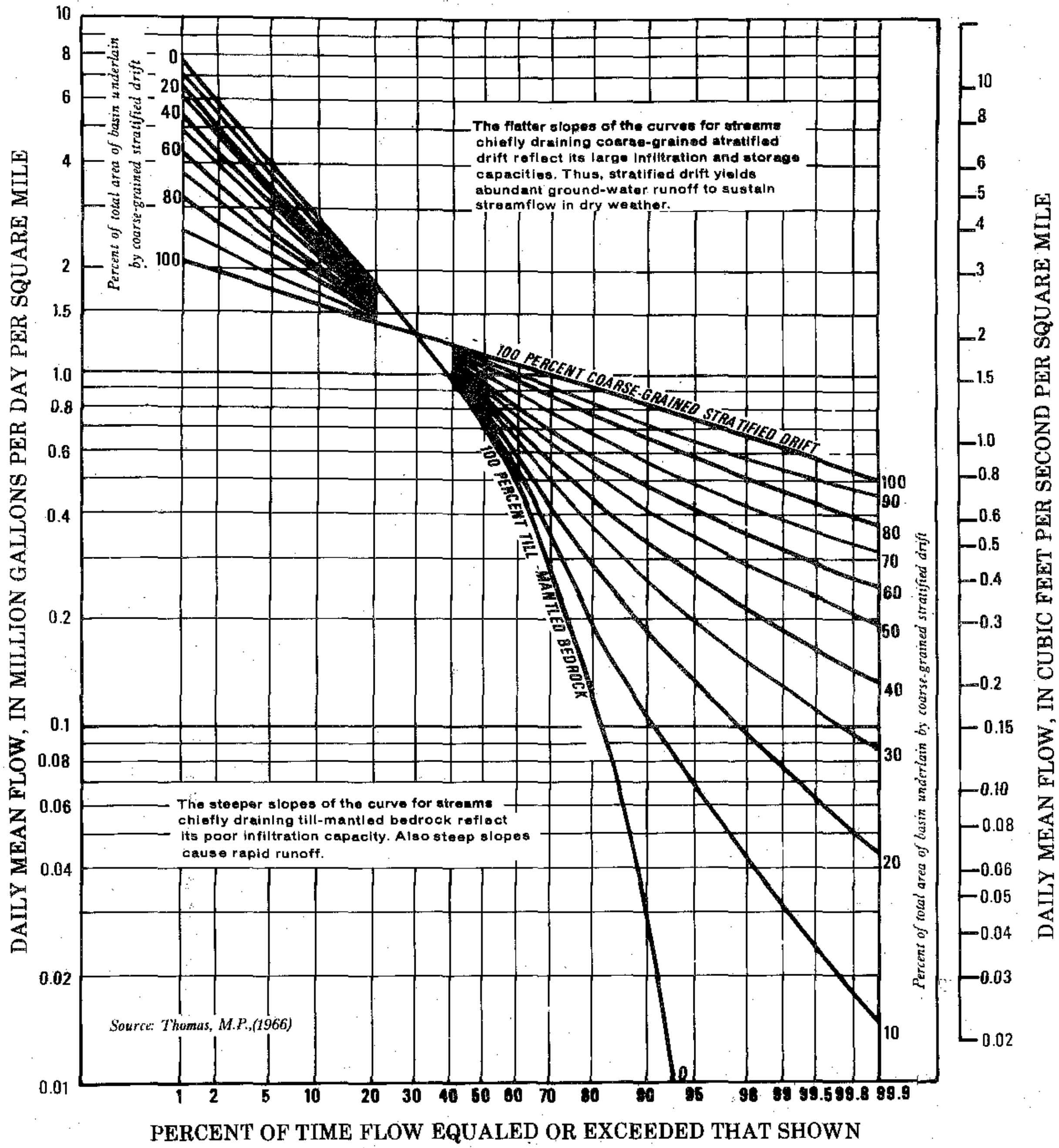


Figure 3.--Regional duration curves showing effects of basin geology on streamflow

Curves are for unregulated streams having a mean flow of 1.16 million gallons per day per square mile and are based on the period October 1930 to September 1960.

Analytical or numerical solutions to ground-water-flow equations can be used to quantify ground-water discharge to streams. The parameters needed for solution of the flow equations such as transmissivity, storage coefficient, and hydraulic gradient are costly to define over large areas. The investigation of flow duration by Thomas (1966) and of frequency and duration of low streamflow (Brackley and Thomas, 1979) used only the areal distribution of the major water-bearing units, parameters that could readily be determined statewide. The method for estimating the 7-day, 10-year low flow outlined in the following section also uses as input the areal distribution of coarse-grained stratified drift and till-mantled bedrock.

A map showing the estimated 7-day, 10-year low flow of streams in part of central New England was prepared by Brackley and Thomas (1979). The flow values on this map are divided into several classes (e.g., "less than 0.1" to "greater than 50" cubic feet per second) and were determined from records of long-term gaging stations, correlation of short-term or partial-record sites with long-term gaging stations, and regional relationships between the total drainage area and flow per square mile from areas underlain by stratified drift and areas underlain by till and bedrock. This report is a continuation of that effort. The focus, however, is on providing a simple method for estimating the 7-day, 10-year low flow at an ungaged site rather than mapping the statewide distribution of this flow characteristic.

REGRESSION ANALYSIS

An effective way for statistically defining the dependency of a streamflow characteristic on one or more independent variables, such as drainage area, average rainfall, or area of stratified drift, is to develop an equation by multiple regression techniques. Once the equation that adequately defines the relationship is derived, the characteristic of interest can be estimated for any site, providing that the site meets the established criteria and that the appropriate values of the independent variables can be determined.

The conceptual model used in the subsequent regression analysis is an outgrowth of Thomas' earlier studies (Thomas, 1966; Thomas and Cervione, 1970) and can be stated as follows: <u>The 7-day, 10-year low flow at any site on a stream is dependent on the proportion of upstream drainage area underlain by coarse-grained stratified drift and the proportion underlain by till-mantled bedrock</u>.

This relatively simple model and resulting analysis incorporates the following assumptions:

1) The 7-day, 10-year low flow at any site on any stream unaffected by man's activities is derived entirely from ground-water runoff.

2) The water-bearing units that contribute to ground-water runoff can be aggregated into two broad classes. The first, termed "coarse-grained stratified drift", is characterized by relatively high ground-water storage per unit area and relatively high transmissivity. The second, termed "till-mantled bedrock," also includes minor areas of fine-grained stratified drift and is characterized by relatively low ground-water storage per unit area and relatively low transmissivity.

3) The magnitude of the 7-day, 10-year low flow is a function of the amount of ground-water runoff from each water-bearing unit and the areal extent of each unit can be used as a surrogate parameter.

4) The extent of the ground-water and surface-water drainage areas contributing to the streamflow are coincident and are defined by the topographic drainage divides.

5) Areal differences in ground-water evapotranspiration are not large enough to affect 7-day, 10-year low flows significantly.

Variables and Data-Selection Criteria

The dependent streamflow characteristic is the 7-day, 10-year low flow (in cubic feet per second) as determined by the log-Pearson type III technique (Riggs, 1968) for 27 stream-gaging stations in Connecticut and nearby parts of adjacent states.

Drainage areas at gaging stations ranged from 0.94 to 132 square miles. The stream-gaging stations used in the analysis and their 7-day, 10-year low flows are listed in table 1; each station is located in figure 4.

The base period to which the flows apply is the reference period April 1, 1941, to March 31, 1971. Fourteen gaging stations had the full 30 years of record; six had between 20 and 30 years of record; and seven had between 10 and 20 years of record. Ten years was considered the minimum record length possible to accurately extrapolate to 30 years.

A correlation technique, based on a comparison of flow-duration curves, was used to determine the reference period 7-day, 10-year low flow at stations with less than the required 30-year record. First, a nearby gaging station with similar geologic characteristics that had been operating throughout the 30-year reference period was selected. Flow duration curves for this long-term station were then plotted for (1) the 30-year reference period and (2) the period concurrent with the record at the station of interest. The two curves were compared and in each case plotted

Table 1.--Gaging stations used for 7-day, 10-year low flow analysis

(Flow data are for reference period April 1, 1941 to March 31, 1971)

USGS Station no.	Gaging station	Drainage area (square miles)	Area underlain by coarse-grained stratified drift (square miles)	Area underlain by till-mantled bedrock (square miles)	7-day, 10-year low flow computed from streamflow records (cubic feet per second)	Record length within the reference period (years)	7-day, 10-year low flow computed by regression equation (cubic feet per second)
01119500	Willimantic River nr South Coventry, CT	122	21.5	100	14	30	15
01120500	Stafford Brook nr Woodstock Valley, CT	4.15	0.04	4.11	0	20	0.07
01121000	Mount Hope River nr Warrenville, CT	28.6	1.2	27.4	0.8	30	1.1
01123000	Little River nr Hanover, CT	30.4	5.3	25.1	4.6	20	3.8
01165500	Moss Brook at Wendall Depot, MA	12.3	.8	11.5	.5	30	.7
01169000	North River at Shattuckville, MA	88.4	3.6	84.8	7.4	30	3.3
01180000	Sykes Brook at Knightville, MA	1.64	0	1.64	.05	25	.02
01181000	West Branch Westfield River at Huntington, MA	93.7	2.1	91.6	5.0	30	2.3
01184490	Broad Brook at Broad Brook, CT	15.6	5.3	10.3	4.5	10	3.7
01187400	Valley Brook nr West Hartland, CT	7.33	.50	6.83	.2	30	.4
01187800	Nepaug River nr Nepaug, CT	23.5	3.9	19.6	2.3	30	2.8
01188000	Burlington Brook nr Burlington, CT	4.13	1.37	2.76	.6	30	.9
01189000	Pequabuck River at Forestville, CT	45.4	16.0	29.4	13	30	11
01190200	Mill Brook at Newington, CT	2.65	.75	1.90	.4	13	.5
01192600	South Branch Salmon Brook at Buckingham, CT	.94	.50	.44	.3	10	.3
01192650	Roaring Brook at Hopewell, CT	24.3	6.7	17.6	4.3	10	4.7
01193800	Hemlock Valley Brook nr Hadlyme, CT	2.62	.23	2.39	.2	10	.2
01196500	Quinnipiac River at Wallingford, CT	110	42.7	67.3	30	30	29
01198500	Blackberry River at Canaan, CT	45.9	6.0	39.9	3.0	22	4.4
01199200	Guinea Brook at Ellsworth, CT	3.50	0	3.50	0	10	.04
01201500	Still River nr Lanesville, CT	67.5	19.5	48.0	15	30	14
01203000	Shepaug River nr Roxbury, CT	132	11.3	121	5.3	30	8.8
01204000	Pomperaug River at Southbury, CT	75.0	9.8	65.2	5.8	30	7.2
01204800	Coppermill Brook nr Monroe, CT	2.45	.37	2.08	.08	13	.2
01206400	Leadmine Brook nr Harwinton, CT	19.6	1.12	18.5	.5	30	.9
01300000	Blind Brook at Rye, NY	9.20	.23	8.97	.4	27	.2
01300500	Beaver Swamp Brook at Mamaroneck, NY	4.71	.24	4.47	.06	27	.2

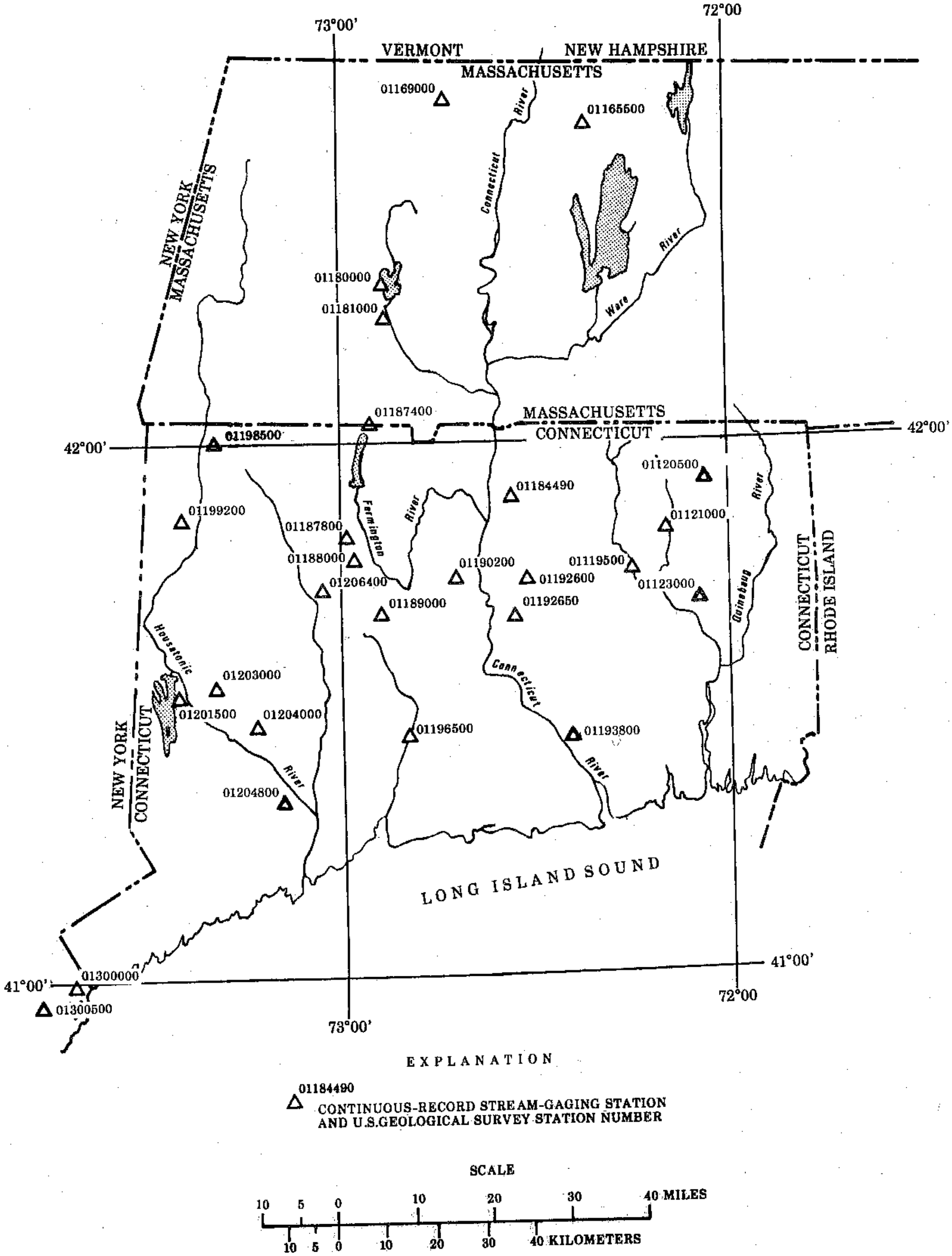


Figure 4.--Streamflow stations used in regression analysis

parallel, indicating a similar distribution of streamflow for both the reference period and the shorter concurrent period. This same relationship between flows for the reference period and the shorter time period was assumed to exist for the station of interest and a flow-duration curve for its period of record was constructed.

Data from the long-term stations used in this study show that the 7-day, 10-year low flow for the 30-year reference period and for the shorter concurrent periods of record are approximately equivalent to the 99-percent duration flow. Accordingly, the 99-percent duration flow at the short-term station of interest was adjusted in proportion to the difference between the 99-percent duration flows for the 30-year reference period and the shorter period of concurrent record at the long-term station. The resulting value is the reference period 7-day, 10-year low flow used in subsequent analysis.

The independent variables used in the regression analysis are the area of coarse-grained stratified drift and the area of till-mantled bedrock (both in square miles). The drainage area underlain by each water-bearing unit is given for each gaging station in table 1.

The 27 gaging stations used in the analysis were selected after a careful screening of more than twice that number having long records. Stations were not used if the flow pattern was affected by man's activities, as determined by records from water users and verified by evaluating the lower part of their flow-duration curves. Stations were also not used if their drainage areas were significantly affected by urbanization which reduces infiltration capacity and decreases low flows.

Regression Results

A regression equation that describes a relationship between the 7-day, 10-year low flow at gaging stations and the proportion of upstream drainage area underlain by coarse-grained stratified drift and till-mantled bedrock was computed by a procedure in the Statistical Analysis System Users Guide (Helwig and Council, 1979, p. 391-396) called "Stepwise".

The equation had the form:

$$Q_{7,10} = aA_{sd} + bA_{till},$$

where $Q_{7,10}$ is the 7-day, 10-year low flow, in cubic feet per second; a and b are regression constants; A_{sd} is the drainage area underlain by coarse-grained stratified drift, in square miles; and A_{till} is the drainage area underlain by till-mantled bedrock, in square miles. The model adds the flow contribution from the area of coarse-grained stratified drift to the flow contribution from the area of till-mantled bedrock.

The resultant regression equation is:

$$Q_{7,10} = 0.67A_{sd} + 0.01A_{till},$$

with a standard error of estimate of 1.4 cubic feet per second. The standard error of estimate was computed as

$$Sy = \sqrt{\frac{(Y - Yc)^2}{N - M}}$$

where Sy is the standard error of estimate in cubic feet per second; Y is the value of the 7-day, 10-year low flow computed from the streamflow records at the gaging stations; Yc is the value of the 7-day, 10-year low flow computed by the regression equation; N is the number of gaging stations used in the analysis; and M is the number of lost degrees of freedom (in this case, two). The values of Y and Yc for the 27 gaging stations used in the regression are listed in table 1 and are plotted against each other in figure 5.

This equation is considered suitable for estimating the 7-day, 10-year low flow at ungaged sites, as it represents the actual physical system, expresses the water-yielding characteristics of each major aquifer in realistic proportions, and has a reasonable standard error of estimate. The standard error of estimate reflects (1) the number of stations used, (2) the physical model, and (3) the accuracy of measuring drainage areas and the distribution of geologic materials.

The 7-day, 10-year low flow is dominated by runoff from the coarse-grained stratified-drift aquifer. According to the equation, 0.15 square mile of coarse-grained stratified drift in a drainage basin can yield a 7-day, 10-year low flow of 0.1 cubic foot per second. On the other hand, a 7-day, 10-year low flow of 0.1 cubic foot per second can be expected from a drainage basin underlain exclusively by till-mantled bedrock only if the upstream drainage area is 10 square miles or more.

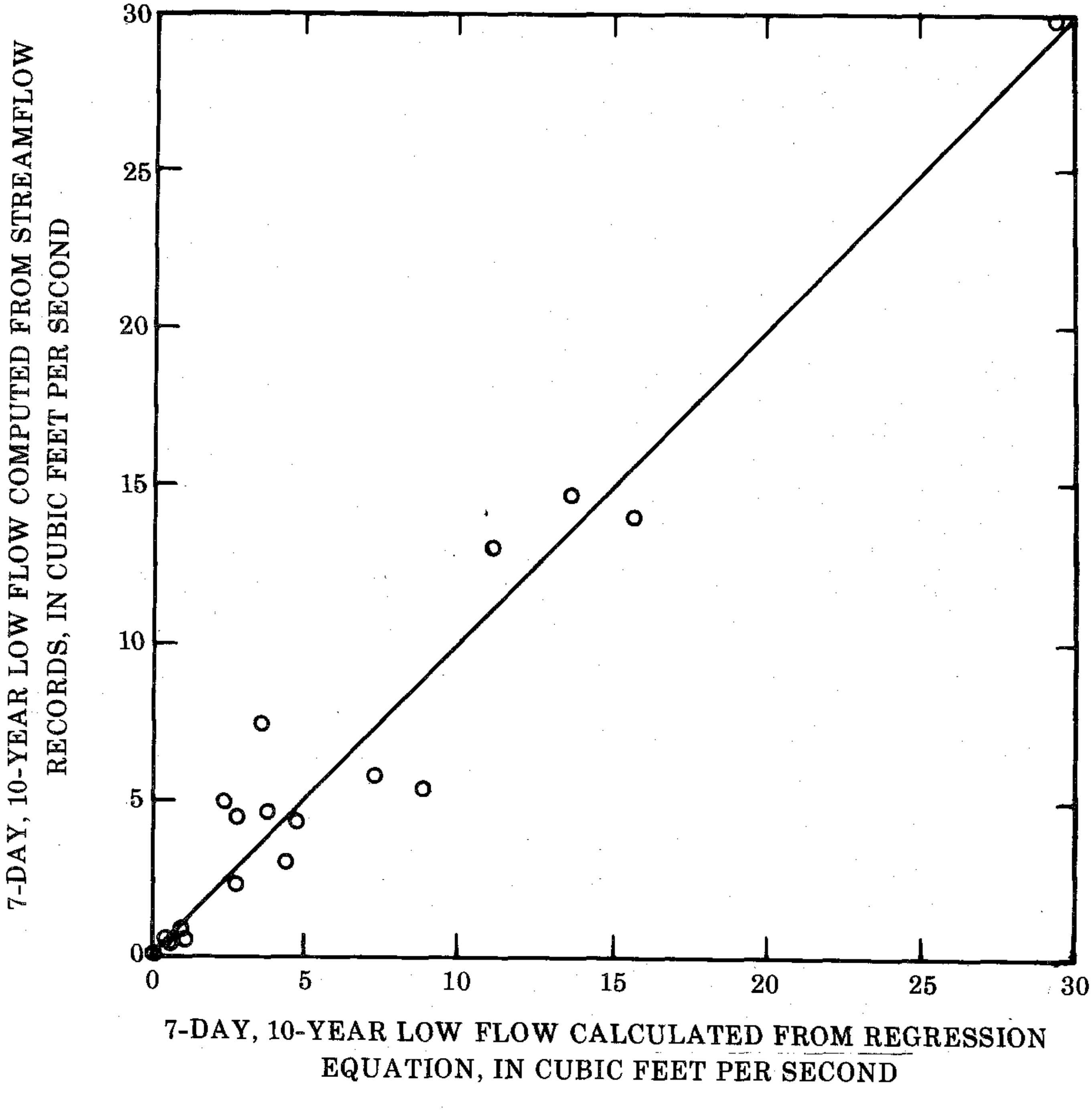


Figure 5.--Observed versus calculated 7-day, 10-year low flows at 27 gaging stations

APPLICATION OF METHOD

The tools required in estimating the 7-day, 10-year low flow at any site on any stream in the State that is not tidal and is not significantly affected by man's activities are the equation given in the previous section, together with a topographic map and a surficial geologic map. The user should be careful to determine that man's activities or urbanization do not significantly affect the low flows of the ungaged stream being studied prior to applying this technique. If the geologic map has a topographic base with contours showing altitude, only that map is required.

A useful set of U.S. Geological Survey 7½-minute topographic maps at a scale of 1:24,000 is on file at the Natural Resources Center of the Connecticut Dept. of Environmental Protection. Basin drainage divides have been delineated on this statewide set of small scale maps.

Figure 6 illustrates the method of estimating the 7-day, 10-year low flow at an ungaged site. The site selected as an example is on the Skungamaug River at State Highway 31 near North Coventry. The segment of the geologic map used in figure 6 was taken from a map showing textures of unconsolidated materials in the Connecticut Valley urban area (Stone and others, 1979). Because this map has contours indicating altitude of land surface and shows areas underlain by coarse-grained stratified drift, it is the only map required. This map is of a convenient size (scale of 1:125,000) to serve as an illustration for a basin having a drainage area of nearly 25 square miles; however, the basin drainage divide and the area of coarse-grained stratified drift can be delineated more accurately on the 1:24,000 scale maps. The 7-day, 10-year low flow is estimated as follows:

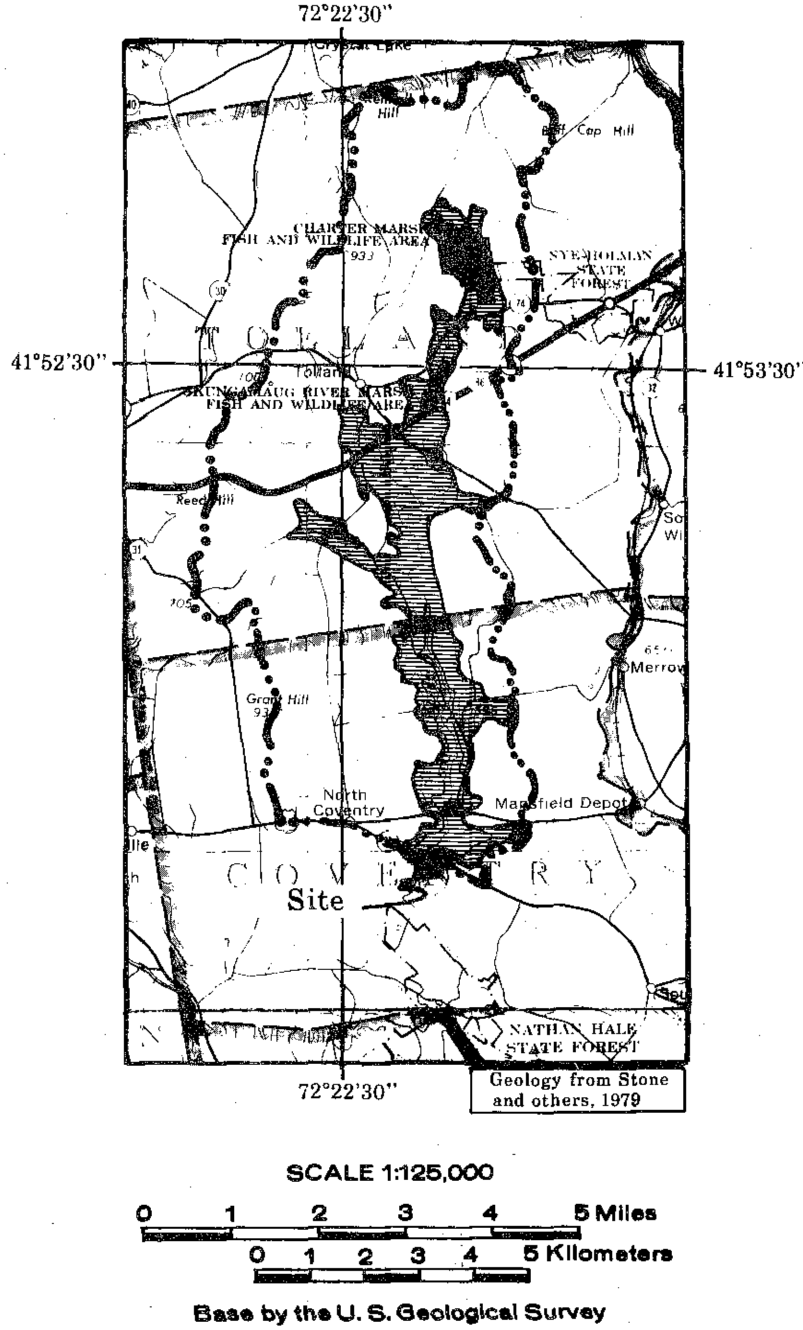
1. The basin drainage divide upstream from the site is drawn on the map by use of the topographic contours.

2. The area enclosed by the drainage divide is measured as 24.7 square miles.

3. The area of coarse-grained stratified drift contained within the drainage divide is measured as 4.7 square miles. The area of till-mantled bedrock is equal to the total drainage area less the area of coarse-grained stratified drift, or 20.0 square miles.

4. The estimating equation to be used is: $Q_{7,10} = 0.67\ A_{sd} + 0.01\ A_{till}$.

5. The estimated 7-day, 10-year low flow is computed to be 3.3 cubic feet per second [$Q_{7,10} = (0.67)(4.7) + (0.01)(20.0) = 3.3$].



EXPLANATION

Coarse-grained stratified drift

Basin drainage divide

EXAMPLE

1. Basin drainage divide is drawn on map.
2. Area enclosed by divide is measured as 24.7 square miles.
3. Area of coarse-grained stratified drift is measured as 4.7 square miles, and area of till-mantled bedrock is 20.0 square miles.
4. Using equation

$$Q7,10 = 0.67\ A_{sd} + 0.01\ A_{till},$$

the estimated Q7,10 =

$0.67(4.7) + 0.01(20.0) =$

3.3 cubic feet per second

Figure 6.--Method of estimating the 7-day, 10-year low flow at an ungaged site

Method is described for a site on the Skungamaug River at State Highway 31 near North Coventry.

SUMMARY AND CONCLUSIONS

The 7-day, 10-year low flow can be estimated for any site on any stream in Connecticut that is not affected by tide, does not have its flow artificially controlled during low flow periods, and does not drain an area having appreciable urbanization.

In Connecticut, low streamflows are sustained by discharge from adjacent aquifers. The aquifers of Connecticut can be categorized in two general groups: coarse-grained stratified drift and till-mantled bedrock. The coarse-grained stratified drift has by far the best water-yielding characteristics. The till-mantled bedrock yields considerably less water to streams at times of low flow; however, it can provide a significant amount of water to streams having large drainage basins.

A regression equation that adequately describes the relationship between the 7-day, 10-year low flow at 27 stream-gaging stations and the proportion of upstream drainage area underlain by coarse-grained stratified drift and till-mantled bedrock was computed. This equation for estimating the 7-day, 10-year low flow at ungaged sites is:

$$Q_{7,10} = 0.67\ A_{sd} + 0.01\ A_{till},$$

where $Q_{7,10}$ is the 7-day, 10-year low flow, in cubic feet per second; A_{sd} is the drainage area underlain by coarse-grained stratified drift, in square miles; and A_{till} is the drainage area underlain by till-mantled bedrock, in square miles. The standard error of estimate is ± 1.4 cubic feet per second.

Drainage basins having much coarse-grained stratified drift will yield relatively large annual low flows. The estimating equation indicates that a drainage basin of only 10 square miles would have a 7-day, 10-year low flow of 6.7 cubic feet per second (a relatively large low flow) if the basin were totally underlain by coarse-grained stratified drift. A basin of the same size, but totally underlain by till-mantled bedrock, would have an estimated 7-day, 10-year low flow of only 0.1 cubic foot per second. Basins lacking coarse-grained stratified drift deposits can yield significant quantities of water if the upstream drainage area is large. A till-mantled bedrock basin having 100 square miles of drainage area would yield a 7-day, 10-year low flow of 1.0 cubic foot per second. However, drainage basins in Connecticut greater than about 20 square miles that are totally underlain by till-mantled bedrock are rare.

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The bulletins in print are for sale by the Department of Environmental Protection, Natural Resources Center, State Office Building, Hartford, CT 06115, telephone 566-3540. Those out of print, indicated by an asterisk (*), are on file for reference at the Center where additional water resource information is available also.

*1. Chemical and physical quality of water resources in Connecticut, 1955-1958; F. H. Pauszek.
*2. Ground-water levels in Connecticut, 1956-1959; A. M. LaSala, Jr.
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